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HONEYWELL INC NEW HOPE MN CERAMICS CENTER
MANUFACTURING METHODS AND TECHNOLOGY FOR PRODUCTION HOT FORGING--ETC(U)
JUN 81 W B HARRISON, J D WEIGNER

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DAAK70-79-C-0138

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REPORT DAAK70-79-C-0138

MANUFACTURING METHODS AND TECHNOLOGY
FOR PRODUCTION HOT FORGING
OF ALKALI HALIDE LENSES

Honeywell Inc.
Ceramics Center
5121 Winnetka Ave North
New Hope, MN 55428

14 478-2

30 Jun 1981
Semiannual Report No. 2
7 April 1980 — 7 April 1981

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Semiannual Report No. 3
7 October 1980 — 7 April 1981

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Prepared for

USAECOM Night Vision and Electro Optic Laboratory
Fort Belvoir, VA

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REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER Semiannual Reports No. 2 and No. 3, DAAK70-79-C-0138	2. GOVT ACCESSION NUMBER <i>AD-A104643</i>	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (AND SUBTITLE) MANUFACTURING METHODS AND TECHNOLOGY FOR PRODUCTION HOT FORGING OF ALKALI HALIDE LENSES		5. TYPE OF REPORT/PERIOD COVERED Semiannual Progress Reports for 7 April 1980 - 7 April 1981
7. AUTHOR(S) William B. Harrison James D. Weigner		6. PERFORMING ORG. REPORT NUMBER 47822
9. PERFORMING ORGANIZATION'S NAME/ADDRESS Honeywell Inc., Defense Electronics Div. Ceramics Center, 5121 Winnetka Ave. North New Hope, MN 55428		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS DD1473
11. CONTROLLING OFFICE NAME/ADDRESS USAECom Night Vision and Electro Optic Laboratory Fort Belvoir, VA		12. REPORT DATE 30 June 1981
14. MONITORING AGENCY NAME/ADDRESS (IF DIFFERENT FROM CONT. OFF.)		13. NUMBER OF PAGES
		15. SECURITY CLASSIFICATION (OF THIS REPORT) UNCLASSIFIED
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE
16. DISTRIBUTION STATEMENT (OF THIS REPORT) Approval for public release; distribution unlimited.		
17. DISTRIBUTION STATEMENT (OF THE ABSTRACT ENTERED IN BLOCK 20, IF DIFFERENT FROM REPORT)		
18. SUPPLEMENTARY NOTES		
19. KEY WORDS (CONTINUE ON REVERSE SIDE IF NECESSARY AND IDENTIFY BY BLOCK NUMBER) IR Optics, Optical Fabrication, Lens Forging, Alkali Halide Lenses, Form-to-Shape Optics, FLIR Systems, Optical Testing		
20. ABSTRACT (CONTINUE ON REVERSE SIDE IF NECESSARY AND IDENTIFY BY BLOCK NUMBER) The hot-forged-to-shape process has been adapted and optimized for the 2 x 3 series/parallel operation. Several of the optimization steps have led to major cost reductions and process simplifications, as well as an increase in the potential production volume. A new type of optical testing equipment is under investigation as a means of evaluating the finished lenses in a production environment. The automation of the process is almost complete and will allow for much finer control of the forging process.		

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Purpose

This project will optimize the manufacturing process and techniques to produce alkali-halide infrared (IR) lenses by the hot forge-to-shape process. This process was developed at the Honeywell Corporate Materials Science Center under Contract DAAK70-77-C-0218, sponsored by Defense Advanced Research Projects Agency and USAECOM Night Vision and Electro Optics Laboratory. The manufacturing techniques under development are intended to be applied to the large family of alkali halide IR materials and, in general, to any other materials which are easily deformed at moderate temperatures.

The particular lens under development is a plano-concave KRR lens designed to replace the ZnSe color corrector lens in the common module IR imager, SU-103/UA. The common module is used in several Forward Looking Infrared (FLIR) systems designed to operate in the 8- to 12-micron wavelength region.

The main tasks in the program are designed to develop and document the production and evaluation processes necessary for a manufacturing environment capable of producing a minimum of 300 lenses per month. Throughout the program several deliveries of lenses are to be made totaling approximately 30 lenses. The major output of the program is to produce the complete description of the developed process and to demonstrate the capabilities of the process.

Section I Engineering Approach

1.1 INTRODUCTION

The goal of the Manufacturing Methods and Technology (MM&T) program is to develop the capacity to produce a minimum of 300 forged KBr plano-concave lenses per month. The forged lenses are intended to replace the ZnSe color correcting lens in the SU-103/UA common module IR imager. Figure 1 shows the lens dimensions and optic layout. With the KBr lens in the imager, the imager specifications are: %MTF on axis - 74%, %MTF off axis - 66%, flange focal length (FFL) - 17.86 ± 0.25 mm and effective focal length (EFL) 67.8 ± 0.7 mm.

This report actually covers two semiannual reports for the periods April 7, 1980 to October 7, 1980 and October 7, 1980 to April 7, 1981. The reason for this is that the optics development group of the Ceramics Center moved to a new facility which caused about a three-month delay due to the moving and installation of existing and new equipment for the program.

During this time some changes have been made or proposed in the contract. For instance, the 3×7 forging process has been eliminated to be replaced by the computer automation of the 2×3 forging process and the purchase of testing equipment for evaluating the lenses. A revised program schedule was submitted in January and is awaiting final approval.

During the time frame covered by this report, all three of the work areas discussed in the first semiannual report were active, that is, the refinement of the forging process, evaluation and testing procedures, and the development of production equipment.

Most of the effort was geared towards the latter two areas as the refining of the forging process is essentially complete.

1.2 REFINEMENT OF THE FORGING PROCESS

The emphasis of the refinement process has been to better the optical quality of the lenses, while at the same time simplifying the process and reducing cost. Throughout the program several breakthroughs have been made towards achieving these goals.

Perhaps the most significant breakthrough has been the complete elimination of helium pressure for forging the lenses. The final lenses are now being forged in air, with no gas pressurization around the forgings. This has eliminated the need for expensive and potentially hazardous high pressure chambers for forging. Not only has this been a major cost reduction but it also implies that virtually any heated press can be adapted to forge KBr lenses with minimal cost. At present, the cost for a complete set of 2×3 tooling

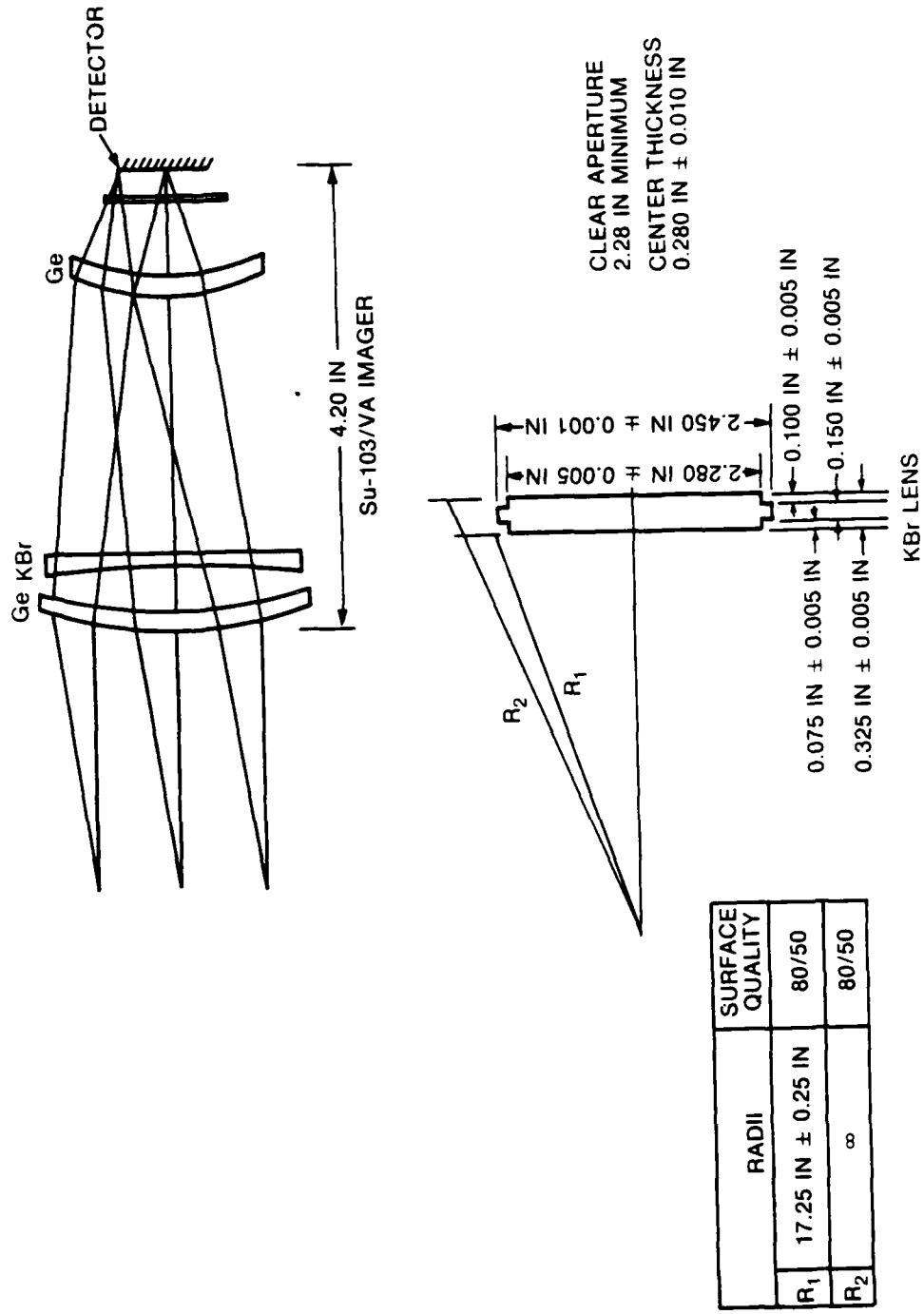


Figure 1. Diagram of SU-103/UA IR Imager and KBr Lens

(three assemblies each with one steel sleeve, two pyrex die sets and three stainless steel rams) is about \$5,000. Our studies indicate that only six sets of 2×3 tooling (18 assemblies) are required to produce the required 300 lenses per month. This will be discussed further under the section on second stage forging, and the program status of the 2×3 process.

Figure 2 illustrates the existing forging process with the current refinements, as well as proposed refinements in the second stage forging process. Most of these refinements are specifically geared towards simplifying the 2×3 process. Some minor refinements have also been made to the first stage forging process.

No changes have been made in the initial inspection procedures as reported in the first semiannual report.

In an attempt to make a major cost reduction and process simplification, a single crystal was forged on pyrex dies to final figure, complete with flange. The resultant lens had a completely formed flange (obtained using steel inserts in the forging sleeve) and the optical surfaces appeared to be completely defect and haze free. However, it has not been ascertained yet whether or not the optic axis is within tolerances, and there are sufficient other problems with this method to prevent its incorporation into the 2×3 process. Experiments with forging single crystals two-high on pyrex dies ended in die failure. The crystals tend to slip to one side during forging creating severe wedging and failure of the dies. It is feasible that a preliminary forging could be done and this in turn forged into a flanged lens. This would completely eliminate the machining step. However, at present, the difficulties in perfecting this process prevent further investigation of this on the present contract. In a production situation, this would be a major area of study for additional cost reductions of the process.

1.2.1 First Stage Forging

Some minor revisions have been made to the first stage forging in order to optimize the entire process. Figure 2 outlines the five steps in the first stage process.

The initial water polish is still performed in the same manner, with a slight cone being formed on both ends of the crystal. However, the starting weight requirement has been reduced from 125 grams to 105 grams. Although no crystals of this weight were on hand, crystals of larger weights were cleaved parallel to the 100 faces, to about 105 grams. These were then water polished in the usual manner, showing that ample material was available to adequately shape the crystal. Another modification has been the reduction of the polished single crystal weight from 92 grams to 89 grams. This reduces the amount of material which must be removed for the second stage forging, which in turn, reduces the overall preparation time, as the removal of material for the second stage forging is much more time consuming than removing material from the single crystal.

It now appears that the aspect ratio is not a critical parameter in the forging process. There does not seem to be any correlation of the residual strain in the lens or the quality

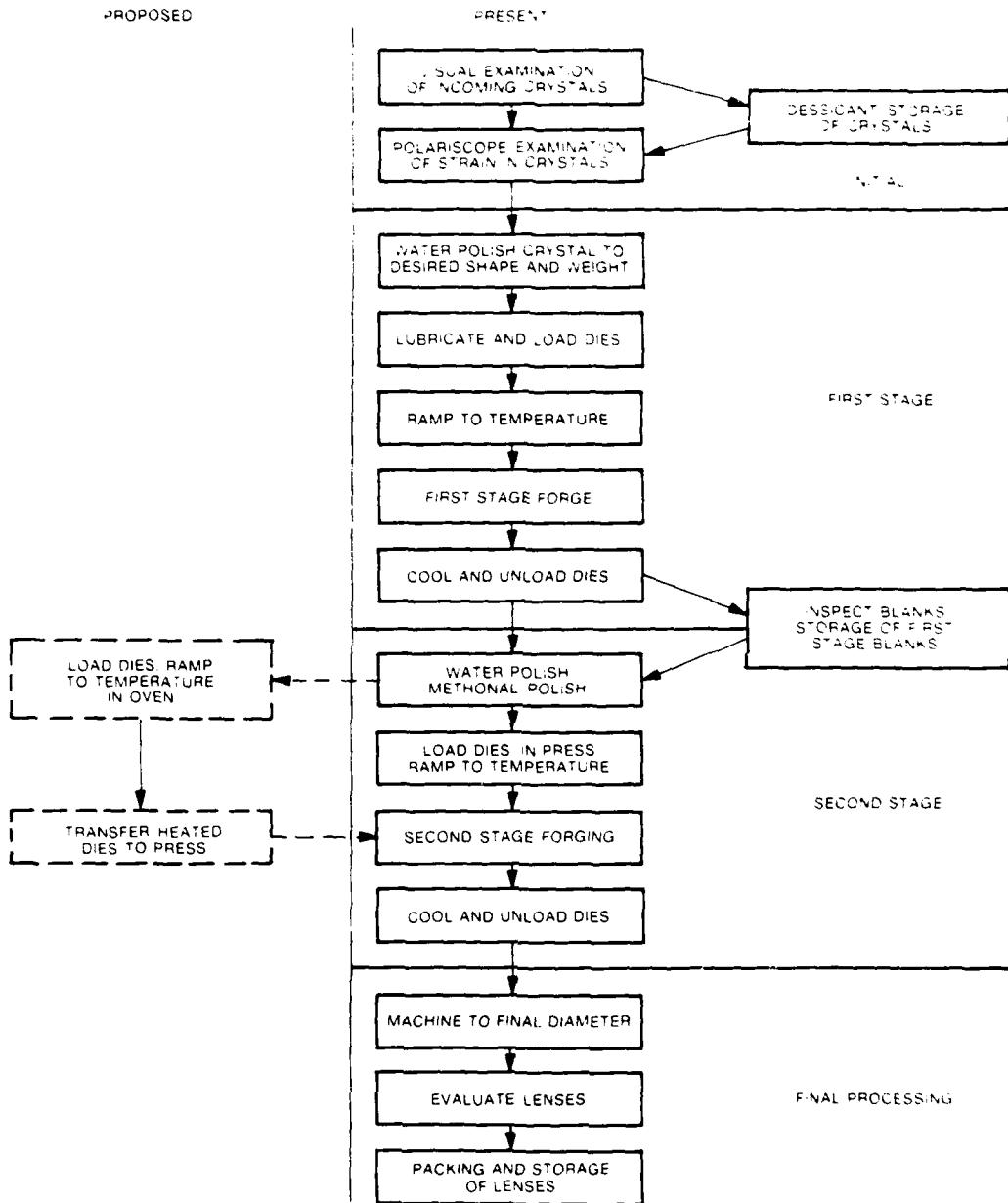


Figure 2. Block Diagram of Forging Process

of the finished lens, to the aspect ratio of the starting crystal. Crystals with aspect ratios as low as 0.75 height/diameter were forged with excellent results and no obvious differences could be seen between these lenses and ones having an aspect ratio of 1.0.

In an attempt to reduce residual strain, cubes of KBr were forged having the x and y axes parallel to the <110>, or easy forging directions. However, examination of the forged cubes indicated that no reduction in strain was obtained and that the strain was much more aligned than in the cylindrical forgings. Therefore, no benefit is seen in using <110> cubes as opposed to cylinders. It would be cheaper from a materials standpoint to use cleaved <100> cubes rather than cylinders. However, because of additional labor involved in preparing the cube for forging, cylinders will continue to be used as the best starting configuration.

It was originally thought that the amount of strain in the starting crystal would reflect the amount of strain in the forged lens, but recent findings indicate that this may not be the case. As indicated in previous reports, the forging rate does have an important bearing on the residual strain in the forging. Figure 3 shows the polariscope strain photographs of 10 KBr starting crystals. The forging identification numbers are indicated in the margins. Figure 4 shows the polariscope strain photographs for five of the first stage forgings. These five (forging numbers 084, 085, 091, and 092) were all loaded into dies and heated in the press at the same time. Upon reaching a temperature of 250°C, numbers 084, 085 and 091 were forged at the same time to 80 percent of final pressure. They were then pressed individually to final pressure (35,000 pounds per 3-in forging) while maintaining the 6.4-percent per minute strain rate. The last two, numbers 092 and 093, were forged individually for the entire forging and at a faster rate (about 10-percent per minute) than the previous three forgings. Both 092 and 093 exhibited high strain after forging (Figure 4) while 084, 085 and 091 showed low strain after forging. When comparing this to the starting crystals, number 092 had high strain before and after forging, while number 093 had low strain initially but high strain after forging.

Figure 5 shows strain photographs of the remaining five forgings. These were all loaded into dies and heated at once. They were then forged one at a time at 6.4 percent per minute strain rate. None of the forgings showed apparent high strain but several of the starting crystals showed significant strain (numbers 089, 090 and very high strain in 087). These results seem to indicate that the initial apparent strain in the starting crystal may actually be reduced in the forging process. However, this is only based on polariscope inspection of the forged lenses and no determination has been made as to whether any effect on the optical properties has occurred. Therefore, polariscope inspection of the crystals is still important as a means of characterizing the crystals and spotting inclusions or flaws in the crystal that may not be visible otherwise. It should also be kept in mind that these conclusions are based on a small sample and that some of the apparent strain reduction is due to the thickness reductions of the crystal. What is more important is the evidence that the constant, lower strain rate does produce very low strain forgings.

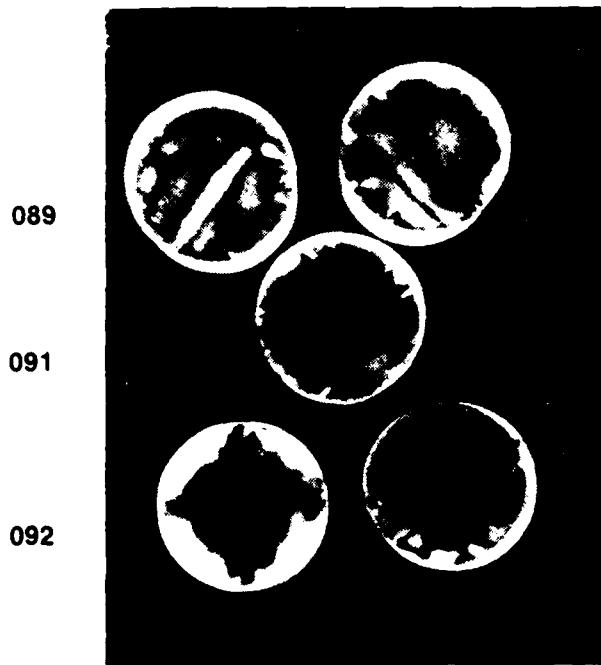
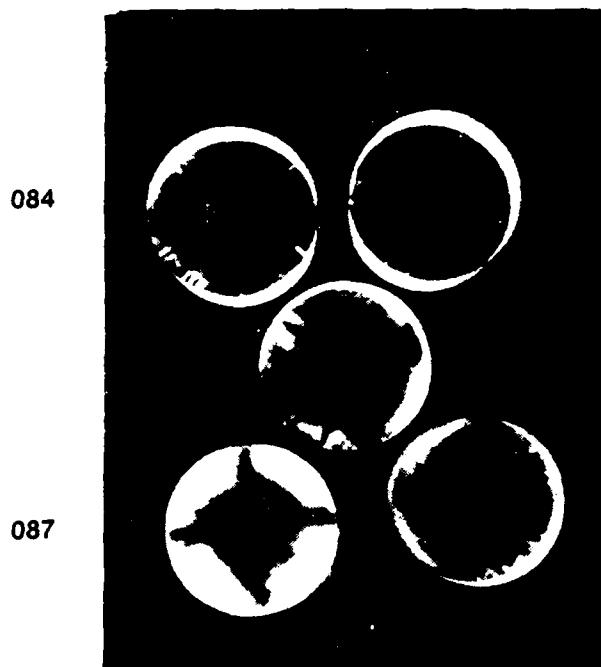


Figure 3. Polariscopic Strain Photographs of 10 KBr Starting Crystals

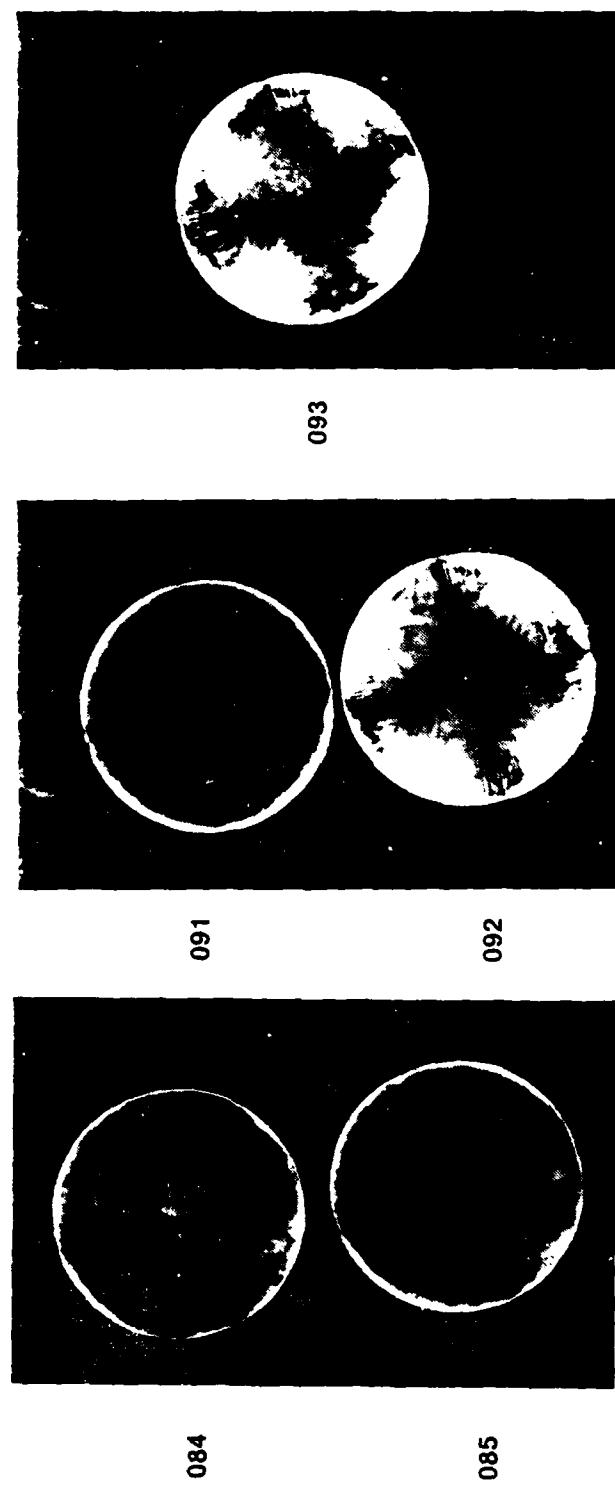
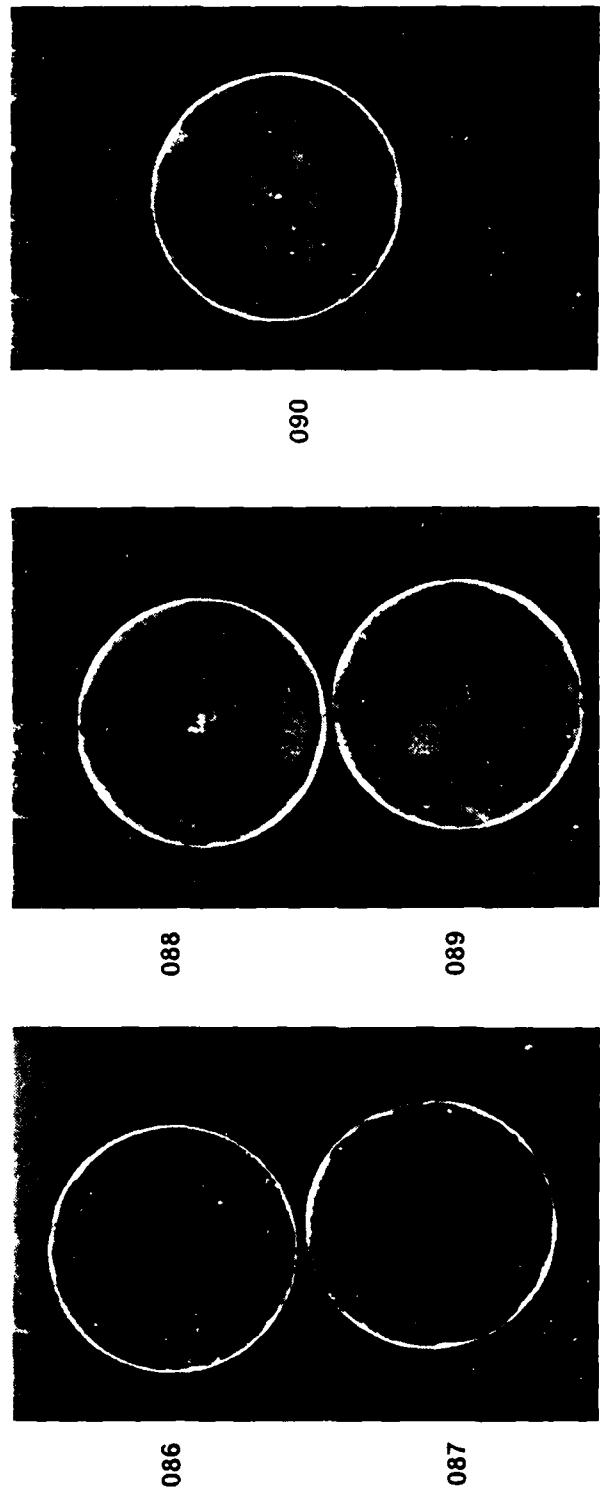


Figure 4. Polariscope Strain Photographs of First Stage Forging Numbers 084,
085, 091, 092, and 093

Figure 5. Polariscopic Strain Photographs of First Stage Forging Numbers 086, 087, 088, 089, and 090



Another revision in the process has been a change in the configuration of the first stage forging. The previous configuration was a double-conical blank. The reason for the double cone configuration was to ensure point contact during the second stage forging process in order to prevent air entrapment. However, after the first stage forging has undergone preparation for final forging, the cones may not be exactly concentric on the blank. When forging against the convex pyrex die in the second stage process, any offset tends to wedge the dies. With two sets of dies stacked on top of each other in the 2×3 process, the wedging can be compounded. The additional tolerances caused by the expansion of the steel sleeves at forging temperatures also contribute to the problem. Figure 6 shows two dies containing small cracks believed to be caused by wedging. The cracks initiated from the sides of the dies and in each case, the die was the upper most die in the forging stack. In an attempt to alleviate the problem, one of the cones on the first stage forging was eliminated. Figure 7 shows a cross-section of the past and present configurations. The flat side of the forging is now placed against the convex pyrex die, which still achieves point contact, but also reduces the wedging problem. The most recent 2×3 forging was done using all plano-conical first stage blanks with no evidence of cracks due to wedging of the dies.

The forgings are being done using 420-F stainless steel dies and hardened AISI type 8140 steel sleeves. The lubrication used is MS-122 fluorocarbon spray.

In an attempt to speed up the production of first stage forgings, hot loading of the single crystals was examined. It was shown that a crystal could be heated independently and transferred to the hot dies without thermal shocking the crystal. However, it is important that lubrication of the dies is maintained. The dies cannot be sprayed while hot, but the crystal can be sprayed before heating. This has been shown to provide adequate lubricant, however, care must be taken in transferring the crystals so as to not wear off any lubricant. It has also been shown that a forged crystal can be removed while

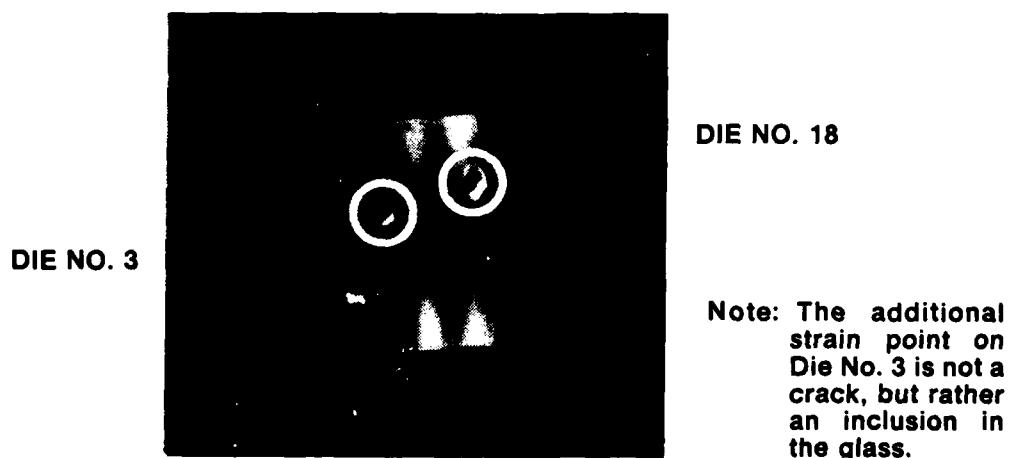
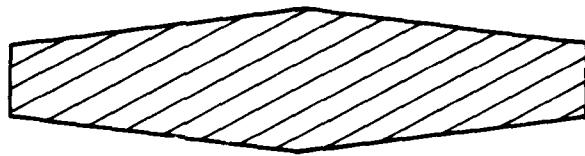
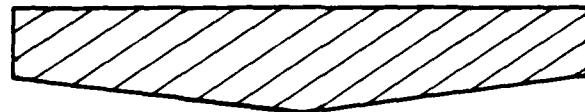


Figure 6. Cracks in Pyrex Dies Due to Wedging



a.) PREVIOUS DOUBLE-CONICAL FORGING



b.) PRESENT PLANO-CONICAL FORGING

Figure 7. Cross-sections of Past and Present First Stage Forging Configurations

hot and placed in a heated environment for slow cooling. However, because of the extra time required and the extreme care with which these methods must be employed so as to prevent thermal shock to the KBr, another approach has been used to speed up the process.

While saving on heating time, the hot loading and unloading of the dies does not reduce the actual forging time, which is a bottleneck in the process. Because of this, a process change was implemented. Enough forging sleeves were purchased so that six forgings could be done in parallel. Due to the differences in crystal weights and die thicknesses, it would be cost prohibitive to do the entire forging operation in parallel. Therefore, the six crystals are forged to 80 percent of final forging pressure (28,000 pounds per crystal) and then forged individually to final pressure. Since the pressure increase is non-linear during forging, most of the forging time has occurred when the crystals have been forged to 80 percent of final pressure. The remaining forging takes about two minutes per crystal. Thus, the total forging time is about 17 minutes for the first forging plus two additional minutes for each additional crystal forged. In a group of six, 15 minutes each is being saved for five crystals or about 75 minutes.

After forging, the dies are removed and allowed to cool for a few minutes on an aluminum plate. The aluminum carries away the heat rapidly, allowing the sleeve and top die to be removed after about 10 minutes. The forging is allowed to cool on the bottom die for another 15 minutes. It can then be removed and placed in a heated chamber for final cooling. Meanwhile, another set of preheated dies and forgings can be loaded into the press and forging can be started. By the time forging is finished on the

second set, the first set can be reloaded and placed in a heating chamber. A third set of dies can then be placed in the press and forged while set two is cooling and set one is heating. In this manner, six forgings of six dies would produce enough lenses (36) for a day's worth of second stage forging, but only three sets of six dies would be necessary to maintain the cycle. It is estimated that four hours of forging time should be adequate to complete the six forging cycles and ten days on a four hour/day schedule (or 40 press hours) would produce the necessary lenses for a month's worth of second stage forgings. In order to minimize tooling costs, only six forgings were being done at once. However, there is no reason to prevent any number of forgings from being done in parallel up to the limit of the press. On this particular press, as many as 20 forgings could be done in parallel. In eight hours of forging time (at 95-percent yield) 150 forgings could be produced in this manner.

Table 1 shows the present, examined, and inherited forging parameters for the first stage process. In summary, the process stands as follows:

1. The incoming crystals are examined and water polished to 89 grams, rounding the corners and introducing a slight cone to each face. Starting weight can be as low as 105 grams.

Table 1. First Stage Forging Parameters Past and Present

Parameter	Present Best Conditions	Past	
		As Inherited	Examined
Isostatic Pressure	1 Atmosphere Air	1 Atmosphere Air	4K psi He
End Forging Load	35,000 lb/3-in forging	35,000 lb/3-in forging	5,000 lb/3-in forging
Temperature	250°C	250°C	275°C, 300°C
Forging Directions	<100>	<100>	<110>, <111>
Input Shape	Cylinder	Cylinder	Cube
Lubrication	Spray Fluorcarbon	Sheet Teflon	Silicon oil, no lubrication
Aspect Ratio	0.8-1.0 height/diameter	1.0	0.77, 0.60
Die Shape	Conical/Flat	Flat	Conical
Die Material	420-F Stainless Steel	Brass	
Sleeve Material	4140 Hardened Steel	Steel	Brass, 420-F Stainless Steel
Forging Speed	6.4-percent constant strain	50 mils/min	Constant strain to 50 percent, ram speeds of 20 and 30 mils/min
Parallel	6 parallel		
Series	1 High	1 High	1 High
Water Polish	Conical ends, rounded corners	Rounded corners	No water polish
Weight Before/After Polish	105/88g	~125/92g	

2. The crystals are preheated to 250°C in steel dies that have been sprayed with MS-122 fluorocarbon lubricant. One die is flat and the other has a 4-degree cone.
3. Six dies are forged one high to 80 percent of final pressure. Each is then forged individually to final pressure.
4. The dies are removed and placed on a large aluminum plate to facilitate cooling. After ten minutes, the sleeve and top ram are removed. Fifteen minutes later, the forging is removed to an isolated chamber for final cooling.
5. The dies are resprayed with lubricant, reloaded, and placed in the preheating chamber.

1.2.2 Second Stage Forging

Very little has been changed in the second stage forging process since the last report. However, much effort has gone into adapting the process to the 2 × 3 forging situation.

The water polishing step is essentially the same as reported earlier, except for the reduction in weight of the first stage forging from 92 grams to 89 grams. This means that only four grams of material need to be removed before forging. It is important to keep in mind that the fluorocarbon lubricant from the first stage must be completely removed from both surfaces of the forging. Experiments indicate that four grams of material is adequate to allow for total lubricant removal, but the weight of the first stage forgings should not drop below 89 grams, as less than four grams excess material may not be enough for lubricant removal.

During water polishing, the forging is held with a vacuum chuck and wiped off with a wet cloth. The forging is immediately blown off with high pressure dry nitrogen, which retards the formation of haze. A methanol polish is then performed to remove any residual haze. This process is very labor intensive, requiring at least 15 minutes per lens. It also requires some degree of skill on the part of the person performing the water polish. An experienced polisher can remove all haze and lubricant while controlling the crystal weight to a tenth of a gram or better, with only four grams excess starting material.

At this point the forging is slightly conical on one face, flat on the other, and weighs about 85 grams.

The blanks are then loaded into the forging assembly as indicated in Figure 8. The convex dies are placed in the down position in contact with the flat side of the KBr blank. This maximizes the stability of the assembly in order to minimize the wedging possibilities. The blanks and dies are blown off with dry nitrogen using an ionizing nozzle to eliminate dust on the surfaces. The steel rams and steel sleeve are sprayed with MS-122 lubricant in such a way that none comes in contact with the Pyrex dies or forging blank surfaces. The entire loading operation is done in a dust-free environment.

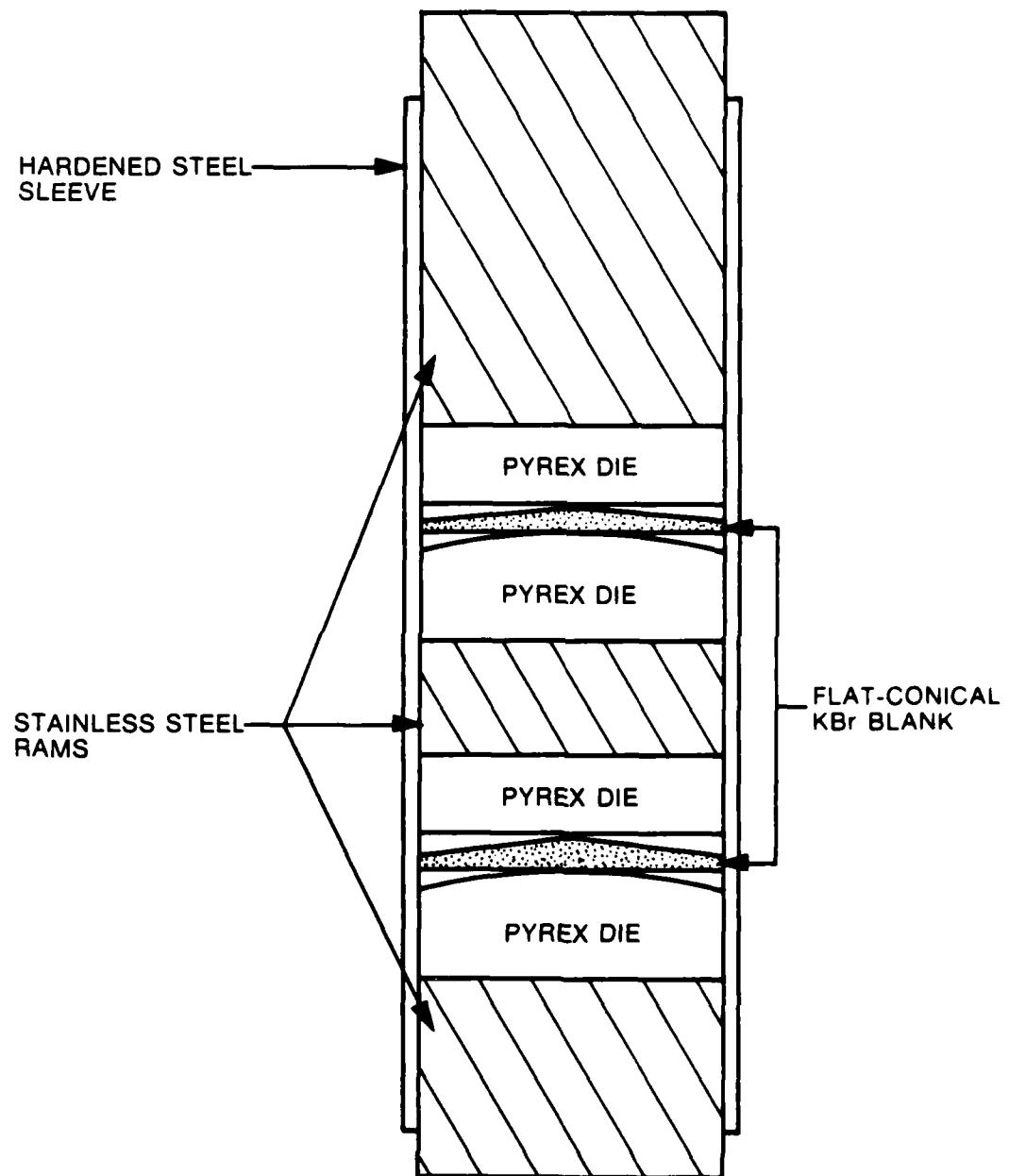


Figure 8. Two-High Forging Configuration

Before a 2×3 assembly is used, the rams and dies must be coordinated in order to have equal heights. The rams and dies are measured and grouped in such a way so that the heights are as close as possible and then shimmed to the same height. When loading with the KBr blanks, the blanks are chosen by weight so that the combined weights of both blanks in each sleeve are approximately equal. The sleeve, die, ram, and shim matching is maintained so that it is not necessary to remeasure each assembly before use. The rams will eventually be reground to eliminate the need for shims.

After loading the assemblies, they are passed through an air lock to the forging area. Preheating ovens are used to preheat the assemblies to 225°C .

The heated assemblies are placed in the press on an aluminum plate. A sheet of 0.040-inch teflon is placed on top of the three forging assemblies. In the event that there is some height difference between the three assemblies, the teflon will tend to deform on the sleeve receiving excessive pressure due to the height difference. This minimizes the problem of die failure due to excessive pressure, as well as allows the remaining two assemblies to undergo final forging as the teflon deforms on the highest sleeve. The entire 2×3 array is then covered with another aluminum plate before forging. Figure 9 shows the complete 2×3 array before forging.

Some thought was given to hot-transfer of the blanks into preheated dies. This would minimize the number of die sets needed for forging. However, the problems involved in handling hot KBr, coupled with maintaining a clean environment, are prohibitive to hot-transfer techniques. Another difficulty arises in maintaining lubrication between the steel rams and sleeve, as the lubricant cannot be applied to hot surfaces. Therefore, the best alternative is to utilize enough preheated die sets so that a batch process will meet

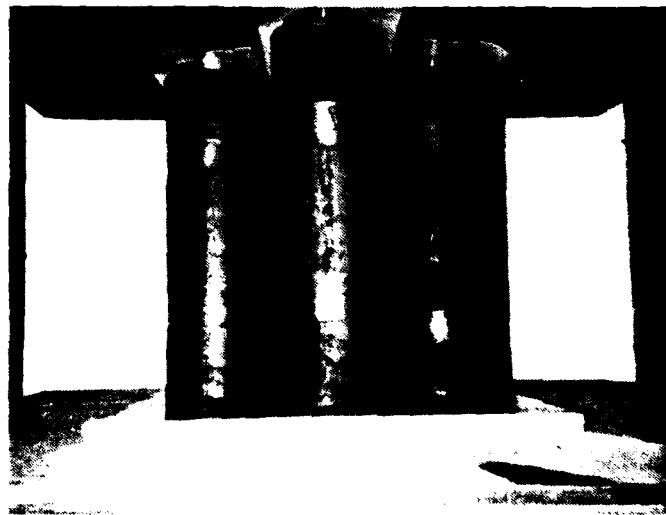


Figure 9. Complete 2×3 Array Before Forging

production capabilities. This can be achieved by using 18 forging assemblies, which is enough for six sets of 2×3 forgings, or 36 lenses. The 18 sleeves can be loaded, heated overnight, and forged the next day. Four hours of forging time will be more than adequate to complete the six sets of forging, and 10 days (40 press hours) on this schedule would produce the month's supply of lenses. As mentioned earlier, the first stage forging would also require 40 hours of press time per month to meet the production quota. Together, only two weeks of press time are required to meet the 300 lenses per month contract requirements. With enough first stage forging dies, the time for forging first stage blanks could be easily reduced, allowing more time for second stage forging. One prediction based on 85-percent yield indicates that with the process as developed using present equipment, a production volume of 900 lenses per month is possible.

The actual forging is done at 0.012in/min (0.006in/min per lens in series). A major cost reduction has been realized in the total elimination of helium pressure, as indicated earlier. The original process used 4000 psi of helium and, until recently, 100 psi of helium was still being used. It has now been shown that no helium is necessary and all 2×3 forgings are being done in air without the use of any pressurizing chamber. The resultant lenses appear to be of exceptional quality.

Another change in the process has been the reduction of the second stage forging pressure from 35,000 pounds per lens to about 31,000 pounds per lens. It is possible that this could be reduced even further. Since the forging is essentially to diameter before forging, it does not require as much force for it to conform to the die shape as compared to a single crystal which must also be forced to move laterally across the die faces.

After forging, the assemblies are removed and allowed to cool in air. Due to the large thermal mass of the assemblies, cool-down is slow enough that thermal shock is not a problem so no advantage is seen in using controlled cool-down.

Figure 10 shows polariscopic strain photographs of six lenses produced in a 2×3 forging using the present process. The strain in each lens is certainly not excessive and fairly uniform from lens to lens. Comparing to the first stage strain photographs (Figures 4 and 5), it can be seen that some increase in strain has occurred. This is most likely due to the lower temperature of the second stage forgings. The reason for the lower temperature (225°C as opposed to the 250°C of first stage forging) is to minimize grain growth and subsequent strength loss in the lens. However, internal deformation becomes more difficult as temperature decreases, hence the strain increase.

Table 2 shows the past and present second stage forging parameters. In summary, the process stands as follows:

1. Water polish and methonal polish first stage forging blanks to 85 grams.
2. Load blanks into sleeve and die assemblies with convex dies in lower positions, flat sides of blank against convex die. The rams and sleeves have been sprayed with lubricant and everything is blown off with dry nitrogen.

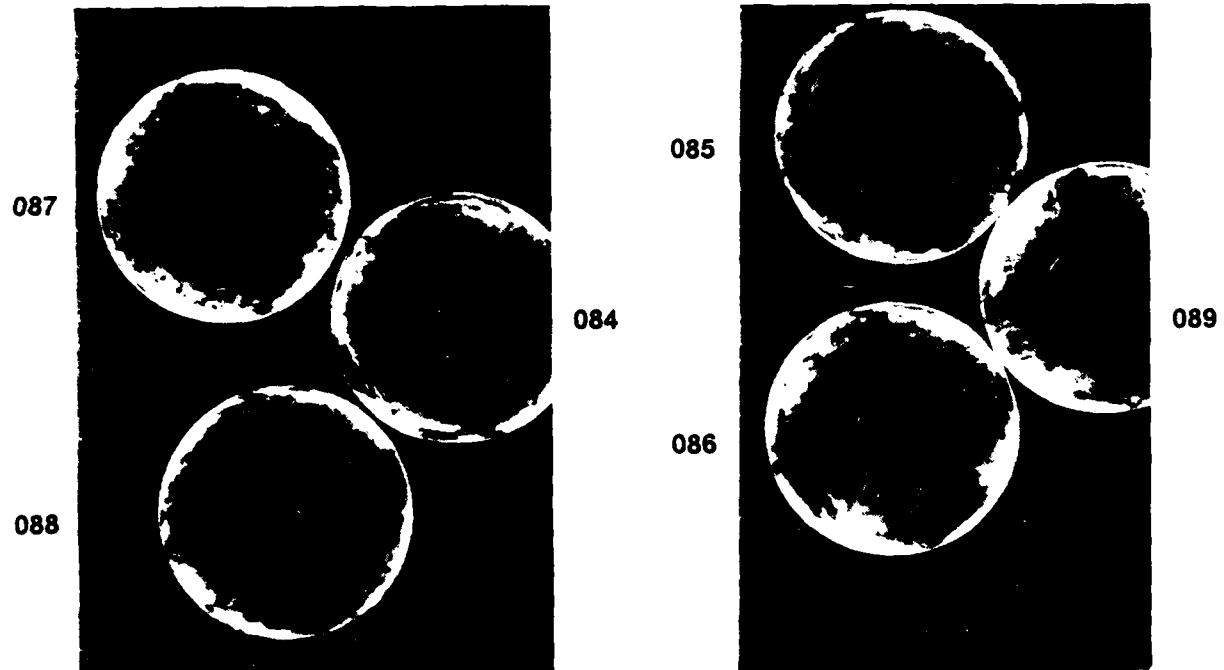


Figure 10. Strain Photographs of Second Stage Forging Numbers 084 through 089

3. Assemblies are placed in a preheated oven and ramped to 225°C.
4. Three assemblies are loaded into the press with aluminum plates top and bottom and a 0.040-in teflon sheet between the top of the assemblies and the top aluminum plate.
5. The forging is done at 0.012in/min to 93,000 pounds total pressure (31,000 pounds per assembly).
6. The assemblies are removed and allowed to cool in air. The next set is then transferred into the press and forged.

1.2.3 Final Processing

After forging, the lens must be machined to final dimensions. The lens is optically aligned on a lathe and machined to size around the optic axis. An experienced operator can align and machine a lens in about 10 minutes. It is a simple process to determine the diameter and flange dimensions using standard contact measuring equipment. However, the center thickness measurement should not be determined using a contact device once the lens has been removed from the forging dies. Therefore, this measurement is best done before removal of the lens from the dies. The height of the dies with the lens can

Table 2. Second Stage Forging Parameters Past and Present

Parameters	Present	Past	
		Inherited	Examined
Isostatic	1 Atmosphere Air	4K psi He	2K psi He, 100 psi He
End Forging Load	31,000 lb/3-in lense	35,000 lb 3-in lense	
Temperature	225°C	225°C	
Pre-machining	None	Machine to conical shape	
Water Polish	Remove fluorcarbon and 4g of material	Remove damage from machining and 10g of material	Remove fluor- carbon and 10g of material
Methonal Polish	Removal of surface haze	Removal of surface haze	
Die Lubrication	None	None	
Sleeve and Ram Lubrication	MS-122		
Die Material	Pyrex	Pyrex	
Sleeve Material	Steel	Steel	
Series Parallel Forging	2 high/3 parallel	1 high/1 parallel	
Forging Speed	0.006 in/min/lense in series (0.012 in/min for 2 high X 3 parallel)	0.006 in/min lense	

be measured by a contact device and the known height of the dies subtracted to find the thinnest dimension of the forging.

1.3 OPTICAL EVALUATION TECHNIQUES

Much consideration has been given to the area of optical evaluation of the lenses. The surface figure, transmission distortion, and $\%_{\text{c}}$ MTF are the desirable parameters to measure on the lens. However, the $\%_{\text{c}}$ MTF measurements are extremely time consuming, which makes the technique unsuitable for production testing. Therefore, it is desirable to compare other measurements on the individual lens to tolerance standards which have been correlated back to the $\%_{\text{c}}$ MTF measurements. This would eliminate the need for the time consuming $\%_{\text{c}}$ MTF measurements on each lens.

Recently, a major step in achieving this capability was the discovery of an optical testing device manufactured by Digital Optics Corporation in Sunnyvale, California. This equipment is a surface interferometer which compares the lens surface to a standard reference surface. Using novel software and evaluation techniques, the device can compare the surface deviation of the lens from the desired surface, thereby meeting the requirement of surface figure measurement. By comparing the lens to radius of curvature tolerance standards, it can be seen if the lens is within this specification. The deviation of the front and back surfaces can be subtracted out to determine the transmission

wavefront distortion due to the lens surfaces. The only requirement which will not be met is the measurement of the transmission losses due to the material itself. A simple transmission test, coupled with these other tests, should be adequate to characterize the lenses. Another major advantage of this equipment is the fast measurement time of only a few minutes to set up a lens and test the surface.

Some tests were performed on the concave surfaces of two lenses, using the equipment under investigation. One lens was supplied by NV&EOL, which had been produced during the first few months of the contract. The other was a lens from the optimized 2 × 3 process (forging No. 084). The lenses were compared to a test plate with radius of curvature of 17.2835 inches. The forging die had a radius of curvature of 17.2805 inches. When the comparison was done, the old lens had a deviation of about 3-1/2 wavelengths of visible light over the central 20-millimeter diameter while the new lens had a deviation of only 1/2 wave. This is some indication of the excellent progress which has been made through optimizing the process parameters.

Figure 11 shows the raw test data output for the new lens. The numbers indicate deviations of the lens from the reference surface (999s indicate pixels outside of the aperture area). The numbers represent 0.02 micron units of deviation in the sagitta. The data can then be displayed on a graphics CRT as a fringe pattern, stored for future use, or otherwise processed. Figures 12 and 13 are contour plots of the deviation (with tilt removed) for lens No. 084. This illustrates just one of the possibilities for processing the data to visually display areas of high deviation.

The equipment shows great potential for measurement of the lenses. In the event that the equipment is obtained for this contract, a large portion of the remaining effort would be to generate the testing procedures and tolerance standards (by correlating to actual MTF measurements) for production evaluation of the lenses.

1.4 EQUIPMENT DESIGN

The major portion of effort in this area has been the design of the automatic equipment required for the forging process. The actual automation has been done with Honeywell funding because the equipment was not bid into the contract. This includes the alterations to the press hydraulics and the electronic equipment necessary to control the press. Figure 14 shows the forging press layout and Figure 15 is a schematic of the automated controls and interfaces between equipment.

The calculator receives the temperature, pressure, and distance parameters, and uses this information to control the forging operation. During second stage forging upon starting the cycle, the press will close to close proximity of the forging rams. The calculator then controls the rate by reading the Acurite Distance Meter over a fixed time base and making current adjustments to the servo metering valve. During this time the pressure and limit switches are being monitored, and when the pressure reaches the desired value, forging stops. After a preset soak time at pressure, the press returns to an open position ready for the next series of forgings.

RUNS.DAT
DO YOU WANT TO NORMALIZE THE DATA? (1=YES, 0=NO): 1

FIT A PLANE TO THE DATA? (1=NO, 0=DO): 0

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ENTER FILENAME:

$$\text{Columns 16 - name file: } \psi = a_0 + a_1 x \quad \left(\begin{array}{l} a_0 = 64 \\ a_1 = -6.75 \end{array} \right)$$

$$SAE(\omega/m_r) = (64 - 1.75 \cdot \tan(\psi))$$

Figure 11. Raw Test Data Output for Lens 084

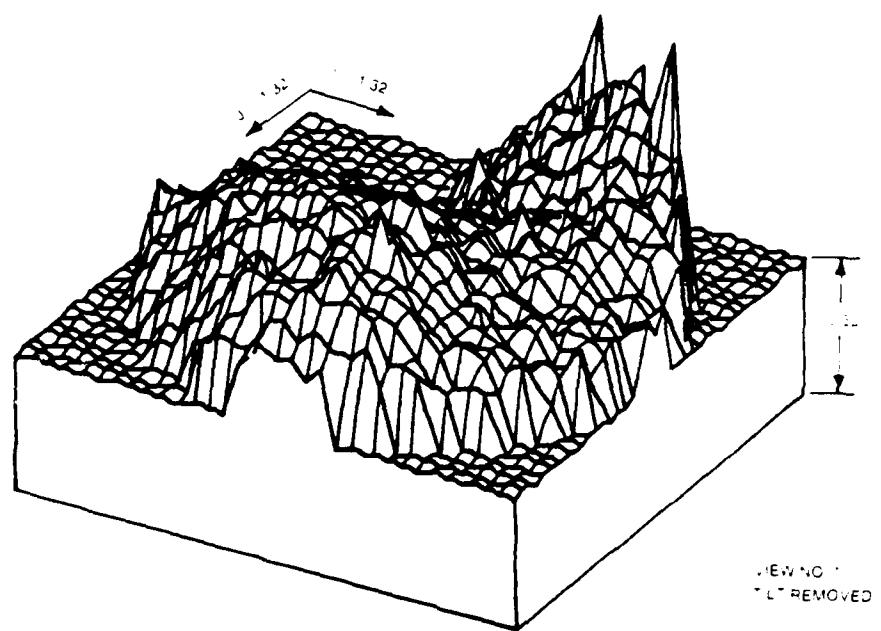


Figure 12. Contour Plot of Concave Surface Deviation of Lens 084

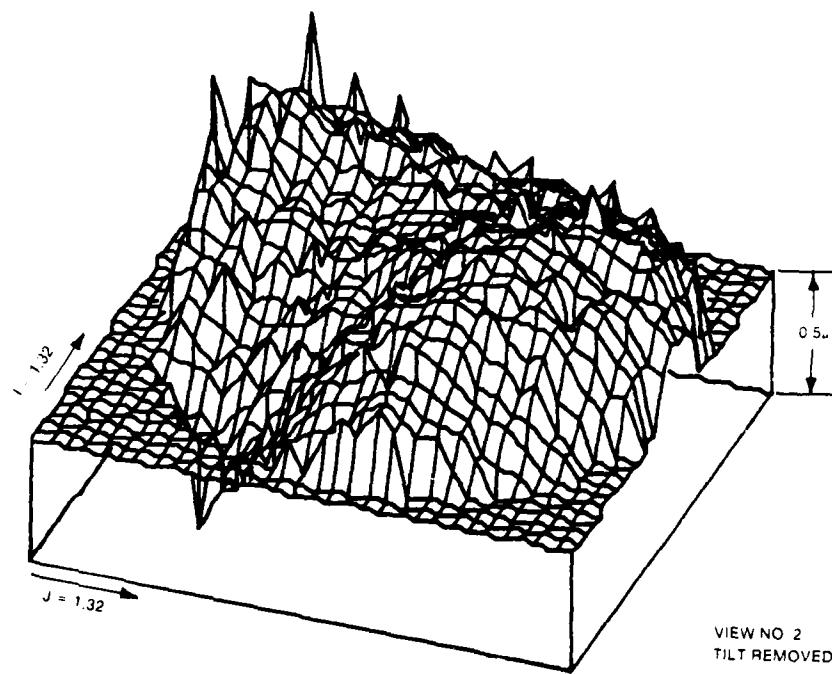


Figure 13. Contour Plot of Concave Surface Deviation of Lens 084 Rotated 90 degrees

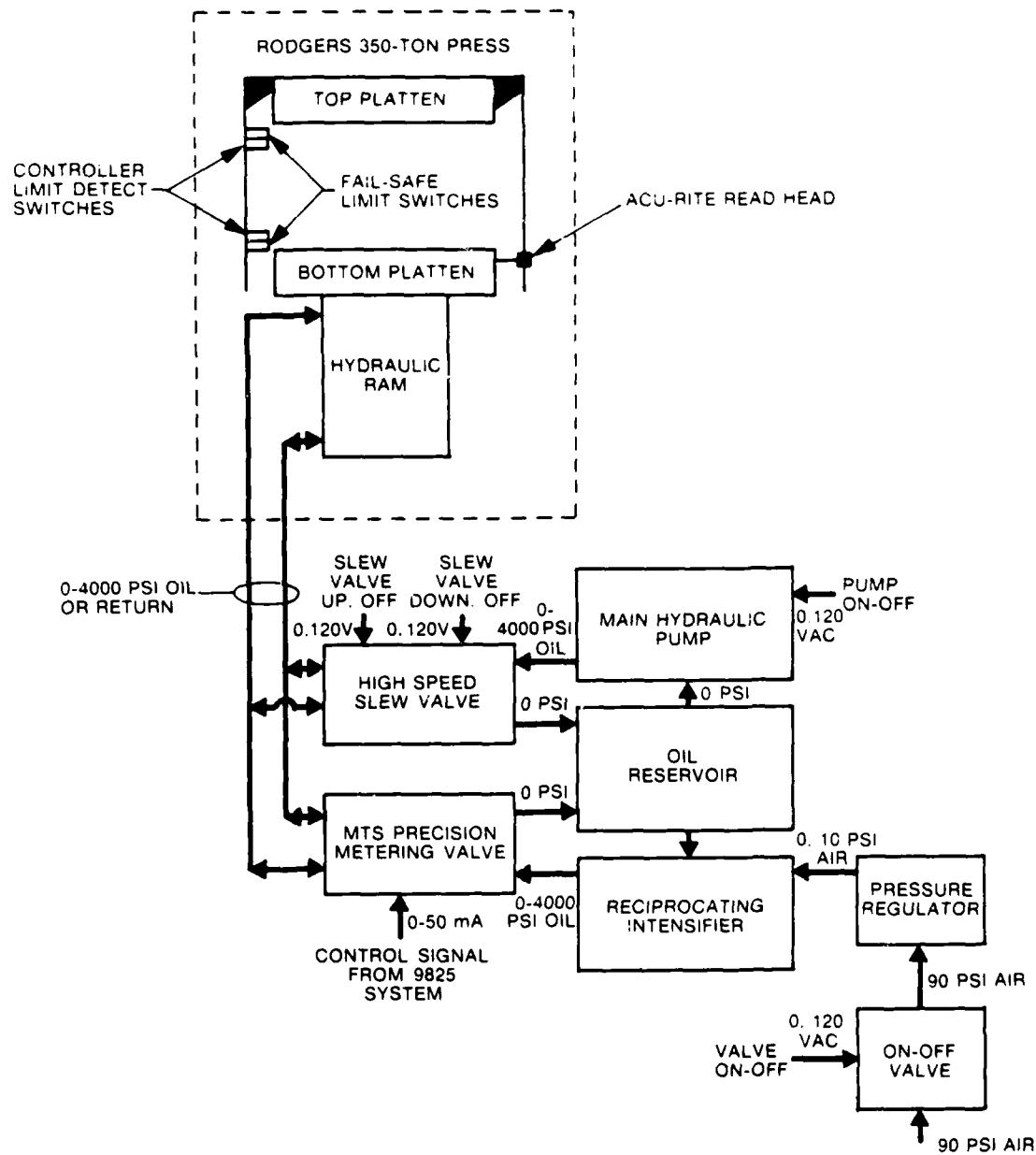


Figure 14. Schematic of Forging Press

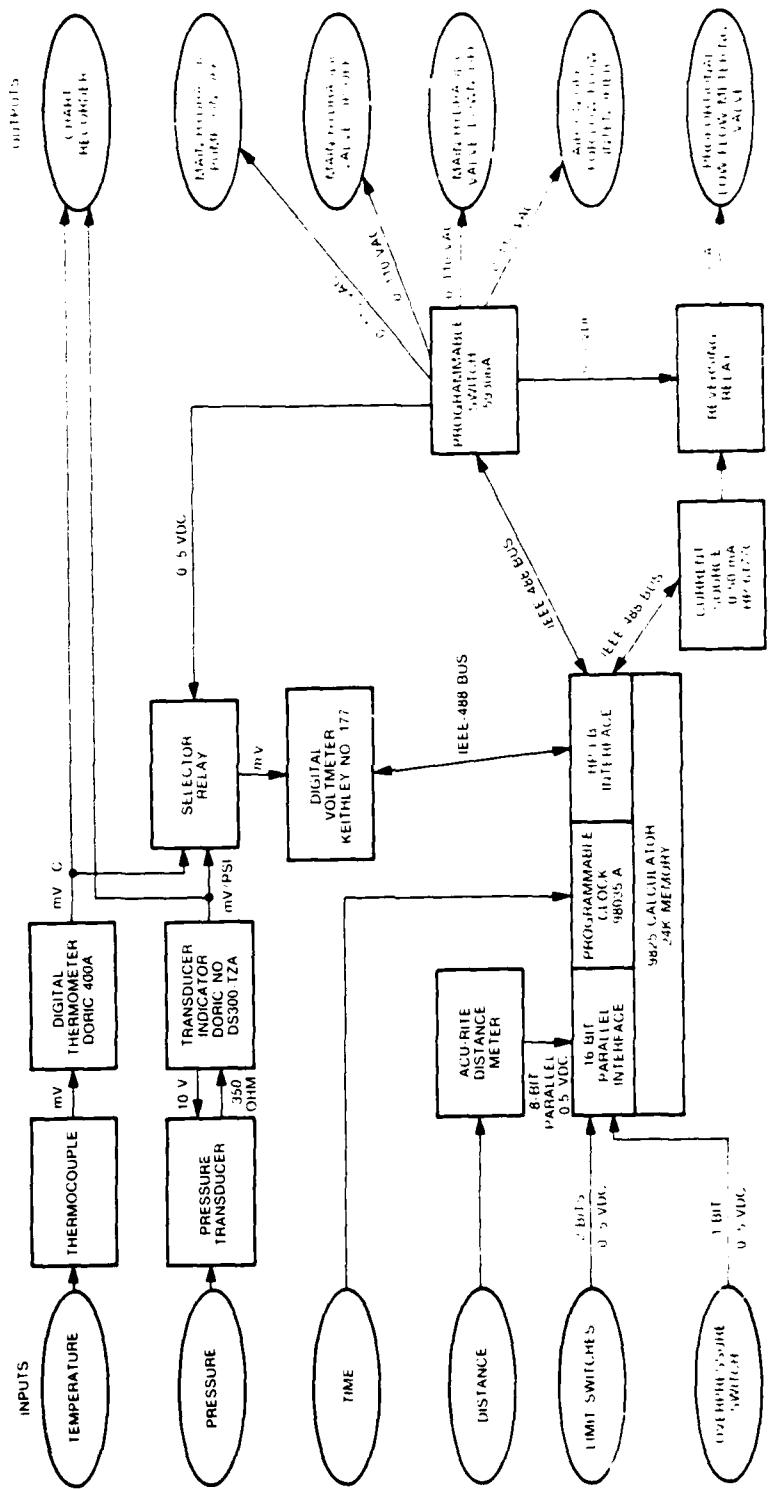


Figure 15. Schematic of Automated Controls

At present, all of the equipment is on hand and being installed (also on Honeywell funds). Work on this portion of the contract will be reactivated with debugging of the automated process. By mid-June the process should be at full capability.

Figure 16 is a photograph of the major press modifications which include the metering valve for controlling the slow forging, the pressure transducer, high pressure filter, and overpressure switch. Figure 17 shows the console containing the calculator, Acurite display, temperature and pressure indicators, current source for the servo valve, programmable switch, and relay indicators.

The initial software has been written and will control the second stage forging operation. Since this forging operation is most critical to the finished lens quality, most of the automation effort has been geared to the second stage process. It will then be a simple and straightforward process to adapt the software to the constant rate first stage forging operation.

Figures 18, 19, and 20 show some of the tooling and equipment used in the forging of KBr lenses. Figure 18 shows the first stage sleeve and dies. Figure 19 shows the second stage sleeve, ram, and dies, and Figure 20 shows the vacuum chuck and high pressure nitrogen blow-off setup, as used for preparing the first stage forging blanks for second stage forging.

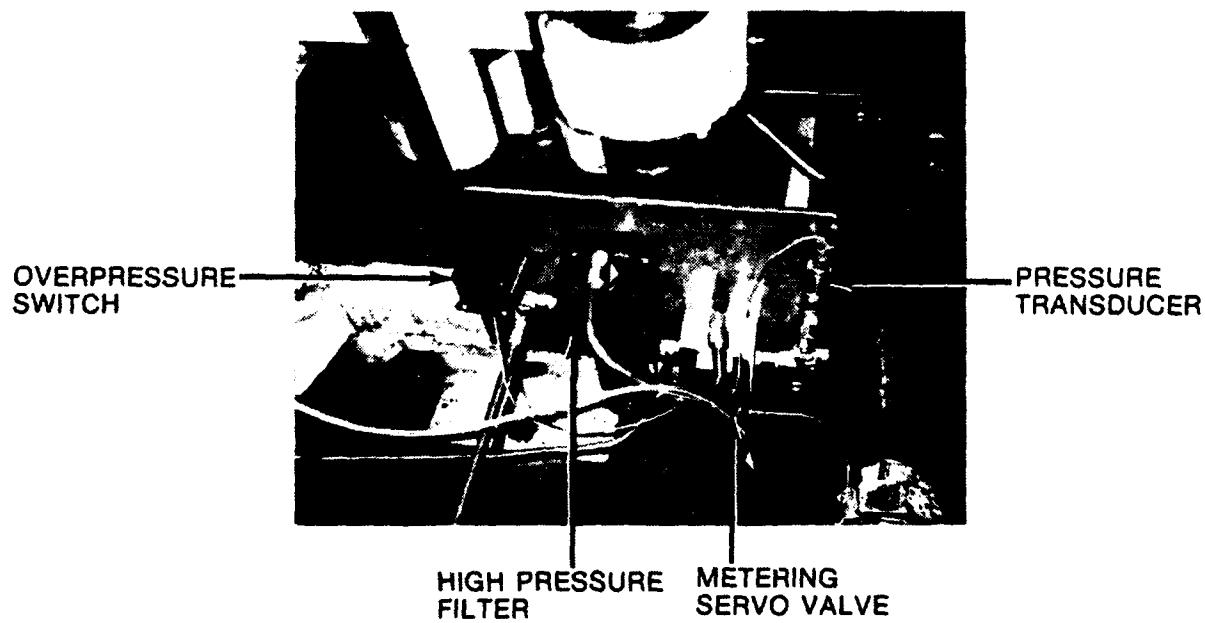


Figure 16. Press Modifications for Automatic Control

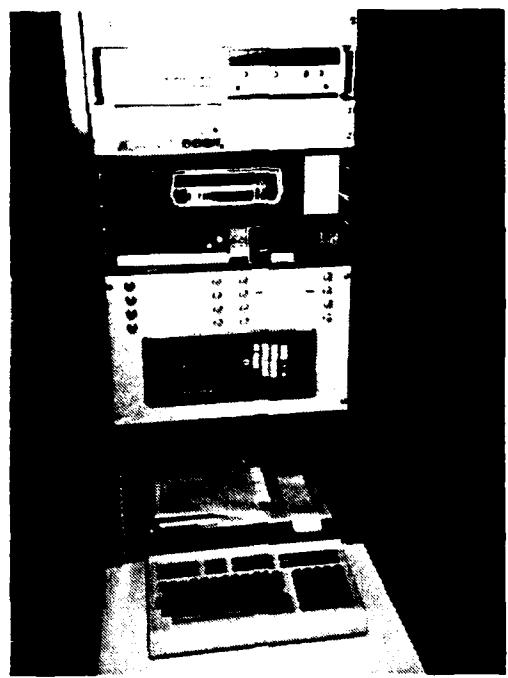


Figure 17. Console Containing Electronic Controls for Press Automation

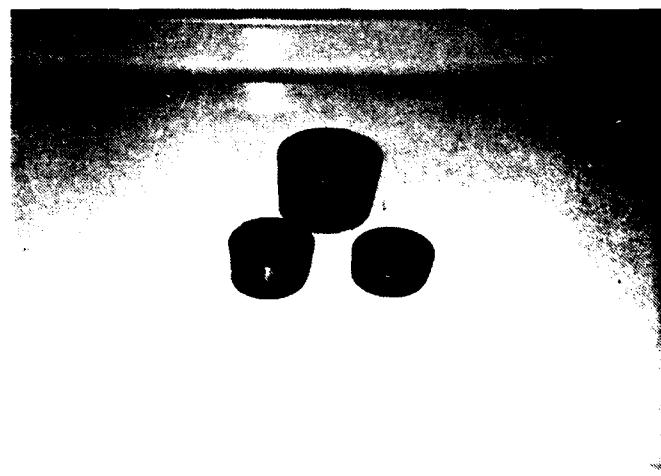


Figure 18. First Stage Forging Sleeve and Dies

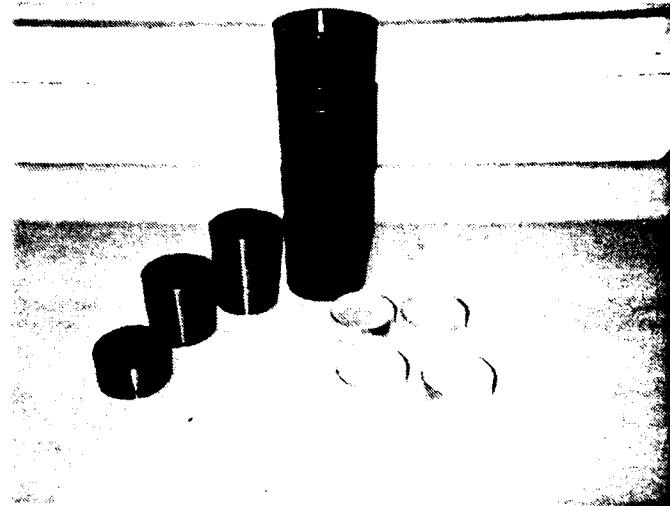


Figure 19. Second Stage Forging Sleeve, Rams, and Pyrex Dies



Figure 20. Vacuum Chuck and Nitrogen Blow off for Preparing Blanks for Second Stage Forging

All of the equipment for producing the lenses is presently on hand, most of which is in operation. The ovens for preheating the assemblies still remain to be installed and should be in operation shortly.

1.5 PROGRAM STATUS

Figure 21 shows the revised program schedule and milestones as submitted to NV&EOL in January 1981. The PERT Chart has also been revised to reflect the changes in the program. Since we now expect to recommend the purchase of the optical evaluation equipment from Digital Optics Corporation as a contractual item, the lead time for delivery is expected to require an extension of those portions of the program dealing with inspection and evaluation techniques. The following is a list of complete or in-progress milestones.

Task 1.0 Process Optimization (Complete)

The process optimization is now complete for the purposes of this program. Exceptional progress has been made in reducing the complexity and cost of the process while improving the lens quality. The process is now to a point where additional refinements, if possible, are beyond the scope of this program.

The first and second stage crystal and forging configurations have been optimized, as well as the forging parameters themselves. Series forging has been demonstrated for the second stage forgings and attempted for first stage forging, but has shown not to be the best approach for first stage forgings. Hot transfer of the crystals to the first stage forging operation has been shown to be feasible but discarded in lieu of hot transfer of the assembled dies and forging in parallel as the best method for production forging. The hot transfer of first stage to the second stage forging operation is not a viable approach; however, the hot transfer of assembled dies has also been shown to be the best method for production of second stage forgings.

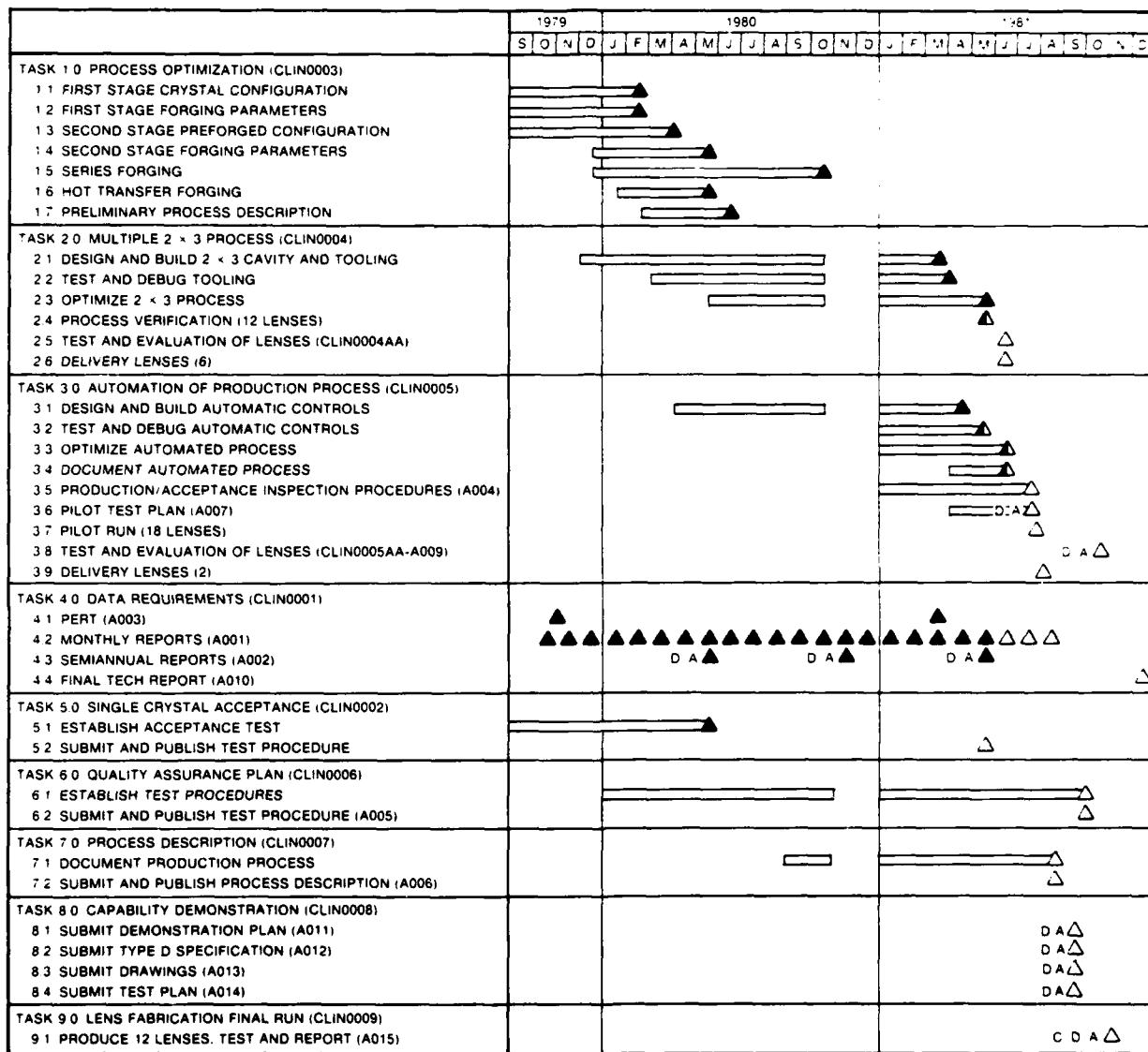
A preliminary process description was written and will be revised in accordance with Task 7.0.

Task 2.0 Multiple 2 × 3 Process

This task is nearing completion. The 2 × 3 tooling has been obtained and tested, and the process has been optimized. Subtasks 2.1, 2.2 and 2.3 are complete.

Subtask 2.4 Process Verification — The 2 × 3 process has already been proven to work; however, an additional forging remains to be done and the lenses must go through optical evaluation.

Subtasks 2.5 Test and Evaluation of Lenses/Delivery of Lenses — The lenses from subtask 2.4 will be evaluated and delivered. However, since the exact testing methods



LEGEND

- C — DEMONSTRATION
- D — DRAFT SUBMITTAL
- A — APPROVAL

Figure 21. Program Schedule and Milestones

for this contract have not been fully determined at present, the methods used to test these lenses may not be the same as the final testing procedures.

Task 3.0 Automation of Production Process

Much has been accomplished towards automating the press. At present, subtask 3.1 is complete and subtask 3.2 is rapidly nearing completion. It is expected that by mid-June the debugging will have been completed and the press will be at full capability.

Subtask 3.3 Optimize Automated Process — The optimization process is a simple matter of adjusting the computer program for the press to meet the requirements of the optimized 2×3 process. Most of this effort will be done in conjunction with the debugging process (subtask 3.2).

Subtask 3.4 Document Automated Process — Documentation is being done in conjunction with the automation and optimization of the automated process.

Subtask 3.5 Production/Acceptance Inspection Procedures — Acceptance procedures are being developed in conjunction with subtask 2.5 and Task 6.0.

Subtask 3.6 Pilot Test Plan — The pilot test plan is being drawn up.

Subtask 3.7 Pilot Run — Inactive.

Subtask 3.8 Test and Evaluation of Lenses — Inactive.

Subtask 3.9 Delivery of Lenses — Inactive.

Task 4.0 Data Requirements

Subtask 4.1 PERT — The PERT Chart has been revised in accordance with the most recent program revisions.

Subtask 4.2 Monthly Reports — All monthly reports prior to this report have been submitted.

Subtask 4.3 Semiannual Reports — This report completes the requirements for the semiannual reports.

Subtask 4.4 Final Technical Report — Inactive.

Task 5.0 Single Crystal Acceptance

The acceptance procedures have been established (subtask 5.1) and will be published shortly (subtask 5.2).

Task 6.0 Quality Assurance Plan

Subtask 6.1 Establish Test Procedures — Several optical testing techniques have been investigated for testing the finished lenses. Presently, the surface interferometer from Digital Optics Corporation is being investigated as the primary testing equipment.

Subtask 6.2 Submit and Publish Test Procedure — Inactive.

Task 7.0 Process Description

Subtask 7.1 Document Production Process — Preliminary documentation of the process has already been done. The documentation is being updated to reflect the refinements in the process.

Subtask 7.2 Submit and Publish Process Description — Inactive.

Task 8.0 Capability Demonstration

Inactive.

Task 9.0 Lens Fabrication Final Run

Inactive.

Section II Conclusions

The MM&T program for hot forging of KBr lenses has been divided into the three areas of process refinement, generation of evaluation techniques, and equipment design. During this program interval of April 7, 1980 to April 7, 1981, most of the effort has been in the areas of process refinement (as specifically applied to the 2×3 process) and equipment design. Some progress was also made in the generation of evaluation techniques.

The process refinements are now complete within the scope of this program. Major cost reductions and process simplifications have been made while improving the lens quality. The 2×3 process has been refined and is now capable of meeting the production requirements of the program.

A major breakthrough in the area of optical evaluation has been the discovery of a sophisticated surface interferometer for testing the lenses. If this equipment is implemented in the program, much of the remaining effort will be geared towards developing the testing procedures on this equipment. The equipment has the potential to quickly and accurately determine the surface quality and surface transmission distortion of the lenses. The use of this equipment along with a simple transmission test should accurately characterize the lenses without actually performing MTF measurements.

The equipment design, having been the major emphasis during this portion of the program, has been completed with the design of the automatic controls for the forging press. The 2×3 tooling is complete, the automatic controls have been designed and built, and final testing and debugging of the automated process is underway.

Section III Program for Next Interval

The primary emphasis for the final portion of the program will be the completion of the optical testing procedures. The investigation of the testing equipment from Digital Optics Corporation has prolonged this area of the program and the procurement of this equipment could possibly extend the completion of this area of the program.

The final debugging and documentation of the automated forging operation will be completed during this time, as will the pilot test run.

Other deliverables will be the capability demonstration, final process description, and the final lens fabrication. The present schedule calls for the final report to be published by December 1981.

Section IV

Publications and Reports

A talk relating to hot forging of KBr lenses was given at the Optical Society of America workshop held at West Falmouth, Massachusetts, on September 21-22, 1980. The paper presented was entitled: **Hot Forging the Infrared Lens: Potassium Bromide**, F.M. Schmit, R.H. Anderson, K.M. Leung, and R.J. Betsch.

The paper is being published in the workshop proceedings. No other reports, talks, or publications concerning this work were given during the current interval.

Section V Identification of Personnel

During this program interval, two personnel changes occurred in the optics group. Dr. Regis Betsch left the optics group in October 1980. James Weigner, who joined the optics groups in June 1980, has been appointed lead project engineer for this program.

The following personnel worked the indicated hours in their respective areas of responsibility.

Individual	Responsibility	Hours 4/7/80-10/7/80	Hours 10/7/80-4/7/81
Roger Anderson	Forging Development and Process Transfer	60	90
Regis Betsch	Overall Engineering Design and Process Development	558	—
William Harrison	Program Manager	147	280
James Weigner	Overall Engineering Design and Process Development	—	678
Rod Luhmann	Optical Polishing, Technician	66	58
Clark Olson	Second Stage Forging, Technician	172	18
Maynard Sandberg	First and Second Stage Forging, Technician	238	270
Fran Schmit	Optical Evaluation	54	40
Optical Design Consultant		66	61
Miscellaneous Quality Assistance		11	9

RESUMES

The following resume introduces the addition of James Weigner to the program. Resumes for continuing personnel were included in the first semiannual report for this contract.

J.D. WEIGNER

Job Title:

Associate Development Engineer

Formal Education:

BS, Ceramic Science and Engineering,
Pennsylvania State University, 1980.

Work Experience:

Mr. Weigner joined the Honeywell Ceramics Center in June of 1980 after completing his degree at Penn State University. His primary area of responsibility is the overall engineering design and process development for the hot forging of KBr infrared lenses. Mr. Weigner is also involved in the development of flexible PZT-rubber composites.

While in college he was engaged in research at the Penn State Materials Research Lab. This research involved the production of ultra-fine reactive beta-alumina and synthetic nuclear waste ceramic powders by evaporative decomposition of solutions.

Appendix A Distribution List

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Optic-Electronic Corporation ATTN: Mr. Bryan Coon 11477 Page Mill Road Dallas, TX 75243	1
Optical Coating Laboratory, Inc. 2789 Giffen Avenue P.O. Box 1599 Santa Rosa, CA 95402	1
Optical Systems and Technology Inc. ATTN: Mr. Harry W.A. Vandermeer 4 Alfred Circle Bedford, MA 01730	1
Rockwell International Corporation Science Center Thousand Oaks, CA	1
Space Optics Research Labs ATTN: Mr. C.A. Pipan 7 Stuart Road Chelmsford, MA 01824	1
Tinsley Laboratories, Inc. 2448 Sixth Street Berkeley, CA 94710	1
Director US Army Night Vision and Electro-optics Laboratory (Quantity 5) ATTN: DELNV-SI (R. Spande) Fort Belvoir, VA 22060	5
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II - VI, Inc. Saxonburg Blvd. Saxonburg, PA 16056	1
Commander US Naval Air Systems Command ATTN: AIR 335 (Mr. E. Cosgrove) Washington, DC 20361	1
Commander Department of the Navy, ELEX 05143A ATTN: A.H. Young Electronics System Command Washington, DC 20360	1

Chief Naval Ship Systems Command Department of the Navy ATTN: Code 681A2b (Mr. L. Gumina) Room 3329 Washington, DC	1
Commander US Navy Weapons Center Michelson Lab ATTN: Code 6018 (H.E. Barnett) China Lake, CA 93555	1
Director Naval Research Laboratory ATTN: Code 2627 Washington, DC 20375	1
Commander US Naval Air Development Center ATTN: Code 202 (Mr. T.J. Shopple) Johnsville, Warminster, PA 18974	1
Commander Naval Ocean Systems Center Code 9254 (ATTN: Mr. Richard Gamble) San Diego, CA 92152	1
Commander US Air Force Materials Laboratory ATTN: AFML/CPO (Mr. D. Fisher) Wright-Patterson AFB Dayton, OH 45433	1
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NASA Scientific and Tech Information Facility P.O. Box 8757 Baltimore/Washington, Int'l Airport	1
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